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Attorney Docket No. 100902

ACOUSTIC RANGING SYSTEM FOR MULTI-LINE TOWED ACOUSTIC ARRAYS

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0002] None.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

[0003] The present invention relates to an acoustic ranging system for multi-line towed acoustic arrays. More particularly, the present invention provides an acoustic ranging system that measures the magnitude of the separation of a pair of towed acoustic line arrays at a discrete point of the array in such a manner as to eliminate a multitude of measuring errors.

(2) Description of the Prior Art

[0004] Towed underwater acoustic sonar arrays are employed onboard surface ships, submarines and unmanned undersea vehicles to detect ships, marine life, marine geology, and other underwater sound sources. The towed sonar array comprises a long cable that trails the employed vehicle when the array is deployed.

[0005] Acoustic sensing elements, called hydrophones, are placed throughout the cable. The hydrophones of the array can be used individually to detect sound sources, but the real value of the hydrophones servicing the array is in the signal processing technique of sonar beamforming.

[0006] Sonar beamforming is a signal processing technique used in acoustic arrays for directional signal reception. The beamforming technique involves combining delayed signals from each hydrophone of the acoustic array at slightly different times, so that every signal reaches the output of the array at exactly the same time, making one loud signal, as if the signal came from a single sensitive hydrophone. By properly selecting the delayed signals, the array under consideration can effectively be steered to enhance the gain in one direction while decreasing gain in other directions. However, the relative position of each individual sensing element, such as

the hydrophone, should be precisely known in order to properly select each time delay.

[0007] In a towed acoustic array that is lying perfectly straight, the positions are fairly straightforward to measure. However, various hydrodynamic forces acting on a towed array as the array travels through the water induce enough movement in the individual sensing elements that a straight-line approximation is no longer valid. Some techniques should be used to estimate the actual positions of the sensing elements and known so-called shape estimators perform this function.

[0008] Typical towed arrays shape estimators perform an integration operation over a combination of parameters, such as pressure (depth) and heading sensors positions located throughout the array, along with tow ship and array physical parameters so as to calculate the positions of the sensing elements. Current techniques are able to provide acceptable error margins for the determination of these positions in most applications for towed arrays.

[0009] In addition to the consideration of the difficulties of the estimation of the actual position of the sensing elements, one of the problems with towed arrays is their so-called left/right ambiguity. Without requesting the tow ship to perform maneuvers, it is difficult if not impossible to know if a sound source is coming from the left or right side of the

array being utilized. More particularly, the beams that are generated by beamforming for an approximately linear array are conical in nature, leading to an ambiguity that rotates a full 360 degrees around the array.

[0010] To combat the ambiguity problem, some modern towed systems employ two or more arrays that are towed alongside each other. In this case, proper beamforming can estimate the relative depth/elevation and unambiguous direction of the sound source. In addition, utilization of the two arrays makes the whole system able to identify a quiet source on one side of the array in the presence of a loud source on the other side of the array. The difficulty with this technique is that the shape of the array estimation becomes more critical.

[0011] Errors that could previously be tolerated in a single array may no longer be acceptable in a multiline system that employs multiple arrays. This non-tolerance is more fully described by authors Cox, H., Lai, H., Heaney, K., & Murray, J. (2003) in the technical article entitled "Hybrid Adaptive Beamforming for Multi-line Arrays" discussed in *Signals, Systems and Computers,* (2003), and included in the *Conference Record of the Thirty-Seventh Asilomar Conference on pages 1858-1862.* As an example for this non-tolerance, a two degree measurement error in heading may not be significant in a single-line system, but in a multi-line system (if the two degree measurement error

occurs) it may cause arrays to cross over each other which can be highly detrimental to the calculations being performed for the multi-line system.

[0012] Accuracy requirements for a multi-line towed acoustic array may be achieved by adding in a system for measuring line-to-line separation at discrete points along the arrays. Current systems do this acoustically, using one array in one line as the transmitter and the other array in the other line as the receiver. Raw data is sent from the measurement station in each line of the array back to the tow vehicle, where the two data sources are compared by means of an envelope correlator contained in the tow vehicle and used with the speed of sound in water to create a range estimate.

[0013] Measurement resolution is based on integration time and signal center frequency. As either of these two parameters increases, resolution improves. Integration time is fixed due to the motion of the array in the water. As the signal center frequency increases, the required data bandwidth servicing a hydrophone increases as well. To make useful measurements, a single range measurement system in a modern multi-line array may require sixteen or more times the bandwidth of a single hydrophone channel.

[0014] Since a number of stations are needed, this required bandwidth puts an extreme load on the array data telemetry

system. Depending on the particular array, range measurement may require tens of kilo-samples per second using conventional techniques. It is therefore desired that a ranging system be provided that uses the equivalent of only a few samples per second.

[0015] To avoid the problems associated with range measurement systems having high bandwidths; a lower-bandwidth alternative to sending raw data can be achieved if the measurement stations in all arrays are synchronized in time. In this case, a unidirectional acoustic signal path is used. One array is the transmitter in one line and another is the receiver in the other line.

[0016] Since the receiver detects when the signal was transmitted because of the synchronization; the receiver is able to calculate transmit time internally and send only the correct result by way of the array telemetry to the tow ship. This solution is not viable in many towed array systems for the reason that synchronization among the engineering sensors (heading, depth, range) is not always guaranteed or achievable. It is desired that a ranging system be provided for multi-line towed acoustic arrays that does not require synchronization between its arrays, while still achieving accurate measurements.

[0017] A further additional consideration for ranging systems for multi-line towed acoustic arrays, is the ability for the

receivers in the source array of the towed arrays to be able to distinguish the arriving signals from; **1)** the transmitted signal emanating from the same hose of the multi-array having provisions for carrying both arriving and transmitting signals; and **2)** the echo from different arrays when there is more than one repeater array present in the system. It is desired that a ranging system be provided for multi-line towed arrays that correctly interprets arriving and transmitted signals carried by the same hose and also correctly interprets echo signals from repeaters in the array.

[0018] Another parameter of interest is the parameter of dissimilar stretches in the towed arrays. Towed arrays stretch when under tension, and imperfect manufacturing tolerances may cause two towed arrays to stretch unevenly. This error, called array skew, increases toward the rear of the array being utilized. The amount of array skew may be calculated from the data that is collected for measuring separation of the elements of the array being utilized. It is desired that a ranging system be provided for multi-line towed acoustic arrays that accommodates for array skew in its measurement technique.

SUMMARY OF THE INVENTION

[0019] Accordingly, it is a general purpose and primary object of the present invention to provide a ranging system for multi-line towed acoustic arrays having a low bandwidth; thereby yielding a relatively low sampling rate for the data being utilized by the ranging system.

[0020] It is a further object of the present invention to provide a ranging system for multi-line towed acoustic arrays that is free of the need for synchronization among sensing and measuring elements.

[0021] It is a still further object of the present invention to provide an acoustic ranging system for multi-line towed acoustic arrays that yields data corresponding to the accurate locations of the sensors being utilized by the ranging system.

[0022] It is a still further object of the present invention to provide an acoustic ranging system for multi-line towed acoustic arrays that accommodates for array skew, so as to yield accurate range measurements.

[0023] In accordance with the present invention, an arrangement comprising a source array and an echo repeater array is provided. Each of the source and echo repeater arrays has a centerline. The source and repeater arrays are separated from each other relative to their centerlines by a distance and by an array skew.

[0024] The source array comprises a signal generator, a transmitter providing an output, and first and second receivers each receiving a signal. The echo repeater array comprises a receiver for receiving the output of the transmitter of the source array, a configurable frequency shifter, and a transmitter for transmitting a signal that is received by the first and second receivers of the source array.

[0025] The arrangement provides a system which measures the magnitude of the separation between the source array and the echo repeater array at a discrete point along the length of each array. The source array acts as the measurement source, while the echo repeater array acts as a configurable frequency-shifted echo repeater. The source array incorporates one sonar transmitter and two sonar receivers.

[0026] The configurable frequency shifter of the echo repeater array enables one measurement source to make measurements, so as to cooperatively operate with multiple repeater arrays, as in a multi-line towed acoustic array system. The arrangement of the present invention, among other benefits, uses several orders of magnitude less digital data bandwidth than prior art systems, while at the same time requiring no synchronization between the source array and the echo repeater array.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] Other objects, features and advantages of the present invention will become apparent upon reference to the following description of the preferred embodiments and to the drawings, wherein corresponding reference characters indicate corresponding parts throughout the several views of the drawings and wherein:

[0028] **FIG. 1** illustrates the arrangement and locations of the components comprising the acoustic ranging system of the present invention; and

[0029] **FIG. 2** is a block diagram of the acoustic ranging system of **FIG. 1.**

DETAILED DESCRIPTION OF THE INVENTION

[0030] Referring now to the drawings and more particularly to **FIG. 1**, there is shown an acoustic ranging system **10** that determines the distance between two towed arrays, that is, a source array **12** and an echo repeater array **14.** This determined distance is required, as will be further described hereinafter, to accurately perform adaptive beamforming used, among other things, to differentiate signals as arriving from the left or from the right of the pair of arrays, **12** and **14.**

[0031] The source array **12** has a centerline **16**, while the echo repeater array **14** has a centerline **18.** The source array **12**

and echo repeater array **14** are separated from each other, relative to their centerlines **16** and **18**, as shown in **FIG. 1**, by a distance **20** and by an array skew **22**. The source array **12** has a signal generator and transmitter **24**, first and second receivers **26** and **28**, whereas the echo repeater array **14** has a receiver **30** that has a configurable frequency shifter to be described with reference to **FIG. 2**. As seen in **FIG. 1**, the signal generator and transmitter **24** transmit an acoustic signal **32** to the receiver **30**, and similarly, the receiver **30** transmits acoustic signals **34** and **36** respectively to receivers **26** and **28**.

[0032] The acoustic ranging system **10**, as will be further described hereinafter, performs an operation without the need of high bandwidth data and without the need of synchronization between the source array **12** and the echo repeater array **14**, while at the same time measuring separation and array skew both measured between the source array and the echo repeater array.

[0033] As seen in **FIG. 2**, the signal generator and transmitter **24** is comprised of a signal generator **38** and transmitter **40** which in actuality is a transducer. The signal generator **38** provides first and second outputs **42** and **44**, wherein the output **42** is routed to a power amplifier **46** which, in turn, provides an output **47** that is routed to the transmitter **40**.

[0034] The second output **44** of signal generator **38** is routed to a first timer **48** and a second timer **50.** The first and second timers **48** and **50** respectively receive input signals **52** and **54,** to be further described hereinafter, that respectively provide output signals **56** and **58** that are both routed to a microprocessor **60.**

[0035] As further seen in **FIG. 2**, the signal generator and transmitter **24** provides an output signal **32** (also shown in **FIG. 1**), via a transmitter **40,** that is an acoustic signal and is received by the receiver **30** (also shown in **FIG. 1**), and in particular receiver **62** (shown in **FIG. 2**), which in actuality is a second transducer. The receiver (transducer) **62** provides an output signal **64** that is routed to a first bandpass filter **66** which, in turn, provides an output signal **68** that is routed to a configurable frequency shifter **70.**

[0036] The configurable frequency shifter **70** is composed of an oscillator **72** having a selectable frequency f_n, and a mixer **74.** The terminology for the configurable frequency shifter **70** is used herein to represent that the frequency f_n may be selected (configured) to meet the operational parameters of the system. The oscillator **72** provides an output signal **76** that is routed to the mixer **74.**

[0037] The output of the configurable frequency shifter **70,** in particular, the mixer **74** provides an output signal **78** that is

routed to a second bandpass filter **80** which, in turn, provides an output signal **82** which, in turn, is routed to a second power amplifier **84.** The power amplifier **84** provides an output signal **86** that is routed to a transmitter **88** (which in actuality is a transducer) and which provides the acoustical signals **34** and **36** (also shown in **FIG. 1**).

[0038] The receiver **26** shown in **FIG. 2**, in particular, a third transducer **90** receives the acoustical signal **34.** The transducer **90** produces an output signal **92** that is routed to a third bandpass filter **94** which, in turn, provides a signal **96** that is routed to replica correlator **98** which, in turn, provides the input signal **52** to the timer **48** - as previously discussed.

[0039] The receiver **28**, in particular, the transducer **100** receives the acoustical signal **36** and provides an output signal **102** that is routed to a fourth bandpass filter **104.** The bandpass filter **104** provides an output signal **106** that is routed to replica correlator **108** which, in turn, provides the input signal **54** to the timer **50** - as previously discussed.

In Operation

[0040] In general, and with reference to **FIG. 2**, two arrays, such as **12** and **14**, from a multi-line system are selected for measurement purposes. Once the arrays **12** and **14** are identified, the signal generator and transmitter **24** projects an acoustic

signal **32** by way of the transmitter **40** (transducer). The transmitted signal **32** is received by receiver **30,** processed and rebroadcast back to be received by the first receiver **26** and the second receiver **28** by way of the acoustic signals **34** and **36** respectively. Calculations are performed by the microprocessor **60** that generate the quantities array separation **20** and array skew **22** (shown in **FIG. 1**). Someone versed in the art can generate these equations using simple geometry. The quantities array separation **20** and array skew **22** are transmitted, via a low bandwidth connection, provided by a conventional array telemetry system back to a signal processor (not shown) onboard the tow ship (not shown).

[0041] More particularly, and again with reference to **FIG. 2**, in the source array **12,** an electronic signal is generated by the signal generator **38** amplified by the power amplifier **46,** converted to acoustic energy by the transmitter (transducer) **40** and transmitted through the water. At the same time the electronic signal generated by the signal generator **38,** by means of the operation of either timer **48**, the receiver **26** and the microprocessor **60** or the timer **50**, the receiver **28** and microprocessor **60,** is put into an replica correlator, contained in the signal processor onboard the tow ship, that is matched to the frequency spectrum of the transmitted signal **32.** In the receiver **30,** the transmitted signal **32** is received, filtered,

frequency-shifted, bandpass-filtered, amplified, converted back to acoustic energy and transmitted as signals **34** and **36** and accepted by receivers **26** and **28**, respectively.

[0042] The receivers **26** and **28** convert the acoustic signals **34** and **36** back to electronic signals, filter, and run the electronic signals through the replica correlators **98** and **108** respectively, with parameters matched to the expected receiver **30** frequency shifted signal created by the operation of the oscillator **72** and mixer **74** comprising the configurable frequency shifter **70**.

[0043] The outputs from the now received quantities, created by the configurable frequency shifter **70** present at the replica correlator **98** and **108** are compared to those derived from the already existing quantities previously formed by the receivers **26** and **28**, the replica correlators **98**, **108** and timers **48** and **50** and calculated with the assistance of microprocessor **60**.

[0044] The microprocessor **60** is used to remove all fixed time delays and leave only the acoustic propagation time. This value is then transmitted by way of the array telemetry (not shown) to be interpreted onboard the tow ship (not shown) in the signal processing equipment (not shown) therein. The signal processing equipment, via techniques known in the art, calculates the distance **20** between arrays **12** and **14**, and also the array skew **22**.

[0045] It should now be appreciated that the practice of the present invention provides an acoustic ranging system for multi-line towed acoustic arrays that accurately measures the magnitude of the separation of a pair of towed acoustic line arrays at a discrete point along the length of each array, while at the same time producing a measurement of the distance **20** separating the arrays **12** and **14** and array skew **22.**

[0046] It should be further appreciated that the practice of the present invention provides an acoustic ranging system for multi-line towed acoustic arrays that can operate regardless of synchronization of towed arrays engineering sensors (known in the art) with respect to each other.

[0047] It should also be appreciated that the practice of the present invention provides an acoustic ranging system for multi-line towed acoustic arrays that may incorporate the feature that by calculating round trip acoustic propagation delay internal to the array comprised of the source array **12** and the echo repeater array **14,** bandwidth requirements are decreased by several orders of magnitude regardless of signal center frequency being utilized

[0048] It should now be still further appreciated that the practice of the present invention provides an acoustic ranging system for multi-line towed acoustic arrays that allows for the

capability to select high transmit frequencies, so as to permit increased measurement accuracy.

[0049] Furthermore, it should now be appreciated that the practice of the present invention provides an acoustic ranging system for multi-line towed acoustic arrays that allows for the capability to select high transmit frequencies, so as to allow shorter integration times and, thus, more range measurement samples per second.

[0050] In addition, it should now be appreciated that the practice of the present invention provides an acoustic ranging system for multi-line towed acoustic arrays that allows for the use of a configurable frequency shifter that permits tailoring of the principles of the invention to service several arrays at once as occurring in multi-line configuration systems.

[0051] Moreover, in addition to above described embodiments, there are a few alternate configurations which can be included as part of the practice of the present invention such as; **1)** the horizontal component of array separation can be calculated from the absolute separation between arrays by incorporating values from nearby pressure sensors; **2)** additional receiver stations can be added to the source array **12** to improve measurement accuracy; **3)** the signal generator **38** can be reprogrammed remotely to upload new transmit signatures, so as to better adapt the practice of the present invention to different

environments; **4)** instead of transmitting back a frequency-shifted version of what it receives, the echo repeater array **14** may have its own replica correlator and signal generator so that it can reply with any preprogrammed signature; and **5)** if there are only two arrays in the system, such as arrays **12** and **14**, the mixer **74** and oscillator **72** can be removed from the receiver **30** to simplify the hardware and software implementation.

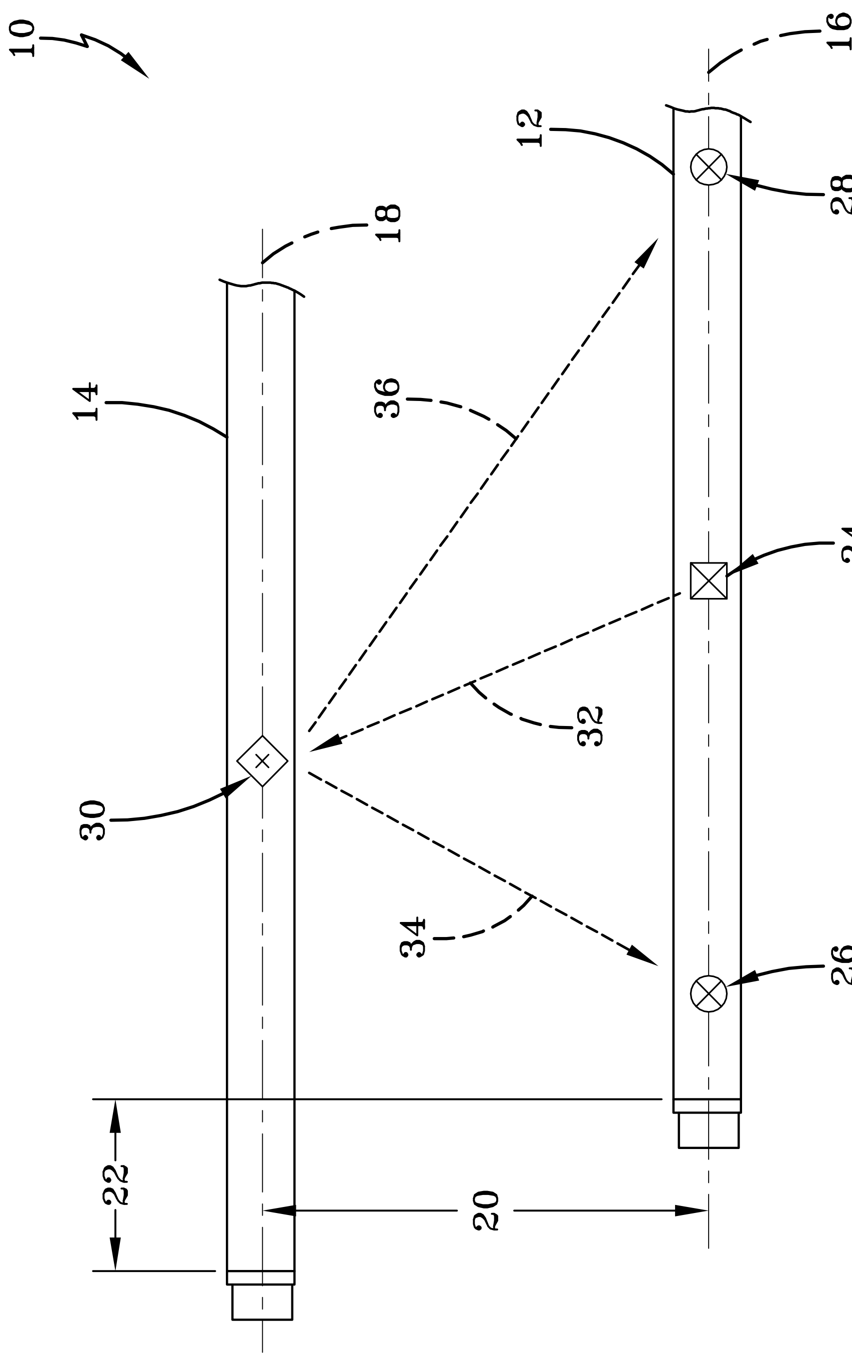
[0052] It will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of that expressed in the appended claims.

Attorney Docket No. 100902

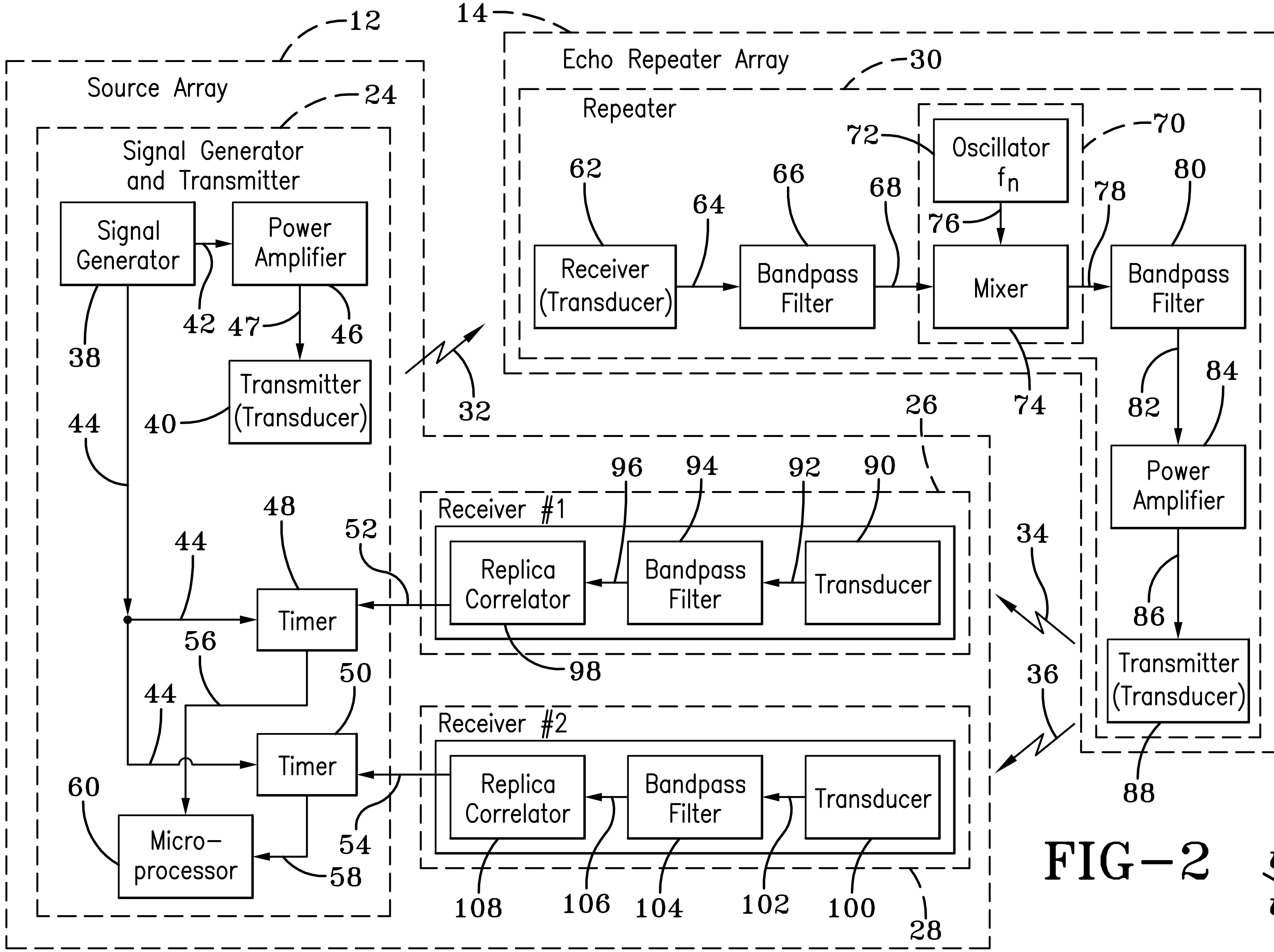
ACOUSTIC RANGING SYSTEM FOR MULTI-LINE TOWED ACOUSTIC ARRAYS

ABSTRACT OF THE DISCLOSURE

An acoustic ranging system and method of use is provided that measures the magnitude of the separation of a pair of towed acoustic line arrays at a discrete point along the length of each array. One array acts as the measurement source, while the other array acts as a frequency-shifted echo repeater. The source array incorporates one sonar transmitter and two sonar receivers. The system further includes a configurable frequency shifter that enables one measurement source to make measurements with multiple repeater arrays.



FIG−1



Source Array
Signal Generator and Transmitter
Signal Generator
Power Amplifier
Transmitter (Transducer)
Timer
Timer
Micro–processor
Echo Repeater Array
Repeater
Oscillator f_n
Receiver (Transducer)
Bandpass Filter
Mixer
Bandpass Filter
Power Amplifier
Transmitter (Transducer)
Receiver #1
Replica Correlator
Bandpass Filter
Transducer
Receiver #2
Replica Correlator
Bandpass Filter
Transducer
12
14
24
30
70
72
62
64
66
68
76
78
80
38
42
47
46
40
44
32
74
82
84
26
96
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92
90
48
52
44
56
50
44
34
98
36
86
60
54
58
88
108
106
104
102
100
28

FIG–2

2/2